ISBN 0-7729-3048-1

THE USE OF GEOPHYSICAL TECHNIQUES IN GROUNDWATER INVESTIGATIONS

SUMMARY REPORT FOR 1986

NOVEMBER 1987

Ontario
Ministry of the Environment

J. Bishop, Director
Water Resources Branch

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IN GROUNDWATER INVESTIGATIONS

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EXECUTIVE SUMMARY

This report describes the geophysical surveys completed by the Geotechnical Services Group of the Drinking Water Section, Water Resources Branch, during 1986. These surveys were conducted in support of groundwater programmes carried out by the Regions. One survey was undertaken for the Ministry of Transportation and Communications.

The surveys completed in 1986 fell in the following categories:

- hydrogeological mapping at landfill sites;
- mapping of groundwater contaminant plumes due to highway salting, salt storage, waste lagoons, and an abandoned coal gasification plant;
- geophysical mapping of formations for stratigraphic correlation;
- locating buried drums and abandoned wells;
- determination of locations of water-bearing zones in a domestic well.

The use of geophysics allowed the investigations to be completed in an efficient and cost-effective manner.

Le présent rapport décrit le résultat des études géophysiques effectuées en 1986 par le Groupe des services géotechniques de la Section de l'eau potable appartenant à la Direction des ressources en eau. Ces études faisaient partie des programmes relatifs aux eaux souterraines mis en oeuvre par les Régions. L'une de ces études a été réalisée pour le ministère des Transports et des Communications.

Les études terminées en 1986 appartiennent aux catégories suivantes :

- établissement des cartes hydrogéologiques de l'emplacement des décharges
- établissement des cartes illustrant les nappes de polluants causées par l'épandage de sel sur les routes, le stockage du sel, les étangs d'eaux usées et les usines de gazéification du charbon abandonnées
- établissement des cartes géophysiques des formations, en vue de la corrélation stratigraphique
- détermination de l'emplacement des barils d'acier enfouis et des puits abandonnés
- détermination de l'emplacement des zones aquifères d'un puits domestique.

Grâce à la géophysique, ces études ont pu être menées de façon efficace et économique.

SUMMARY OF GEOPHYSICAL SURVEYS COMPLETED IN 1986

REQUESTING GROUP	OBJECTIVE OF GEOPHYSICAL SURVEY	RESULTS ACHIEVED
MOE Central Region	Mapping of hydrogeology at existing landfill sites in Bracebridge and Gravenhurst, to allow the determination of the possible mechanism for migration of pollutants from the sites.	Buried bedrock channels located at both sites. These channels could provide possible paths for the migration of pollutants from the sites. Monitoring well locations selected on the basis of geophysical results.
MOE South-Western Region	To locate buried metal structures or waste and to map any waste contaminant plume at the Woodstock Coal Gasification site.	Buried metal structures from abandoned coal-gasification site were located. A contaminant plume was also mapped. This allowed accurate excavation of the buried structures and the installation of wells to monitor the plume.
Ministry of Transportation & Communications	Delineation of area of contaminated groundwater around MTC patrol yard at Hillsdale.	Area of contaminated groundwater mapped and potential impact of salt contamination on domestic wells identified.
MOE West-Central Region	To locate buried waste disposal drums at an unlicensed site near Waterdown.	Drums located and removed by excavation.
MOE South-Western	To locate a buried, abandoned deep disposal well near Sarnia, so that it could be properly sealed.	Well successfully located and sealed. Buried tank full of industrial wastes also located near the well.

REQUESTING GROUP	OBJECTIVE OF GEOPHYSICAL SURVEY	RESULTS ACHIEVED
MOE Central Region	To determine the extent of salt contamination of groundwater due to highway salting near Barrie.	Contaminant plume delineated and impact on domestic wells identified. Replacement well installed.
MOE South-Western Region	Mapping of hydrogeology near Hensall, to determine the mechanism of nitrate contamination of municipal well.	Mapping completed and target areas for installation of monitoring wells selected.
MOE West-Central Region	Mapping of contaminated groundwater around waste oil treatment plant at Breslau.	Area of groundwater contamination delineated.
MOE Central Region	Determination of zones of poor water quality in a domestic well in Orillia.	Zones of poor water quality identified by geophysical well-logging.

GEOPHYSICAL TECHNIQUES

IN GROUNDWATER INVESTIGATIONS

A REVIEW OF CURRENT GEOPHYSICAL METHODS

INTRODUCTION

Geophysical techniques constitute an essential component of groundwater investigations. Some geophysical methods offer a direct means of detecting contaminant plumes from various sources of groundwater contamination. Others offer a way to obtain detailed information about subsurface geology. The capability to characterize the subsurface rapidly without disturbing the site, offers benefits in terms of less costs, less risks, and better understanding of site conditions.

The three general objectives usually involved in subsurface investigations are:

- determination of the presence of plumes and the direction, rate of movement, and distribution of contaminants;
- determination of hydrogeology;
- location of buried materials (e.g. waste disposal drums).

During the past decade, extensive development in remote sensing geophysical equipment has greatly enhanced our ability to meet these objectives. The use of geophysics usually results in substantial cost savings because expensive test drilling can be minimized, and monitoring wells can be installed in the proper locations.

Geophysics has been used for several years in support of the Ministry's groundwater programmes in the Regions and Head Office Branches. These programmes can be classed in the following categories:

(a) mapping, exploration and development of aquifers;
(b) determination of hydrogeology at existing or proposed landfill sites;
(c) location of buried drums and waste containers;
(d) mapping of contaminant plumes in groundwater around landfill sites, highway de-icing operations, salt storage facilities, sewage lagoons, and spills;
(e) determination of zones of poor water quality in wells.

THE GEOPHYSICAL TECHNIQUES

The principal geophysical methods used in groundwater investigations are:

- Seismic Refraction
- Earth Resistivity
- Inductive Electromagnetics (EM)
- Gravity
- Magnetometry
- Geophysical well-logging

The main applications of these methods are summarized below:

Application:	Methods That Can Be Used:
Mapping hydrogeology	Seismic, resistivity, gravity, EM
Mapping contaminant plumes from landfill sites, etc.	EM, resistivity
Location of buried metal objects	Magnetometer, EM
Determination of zones of poor water-quality in wells	Geophysical well-logging

The Seismic Refraction Method

The seismic refraction technique is used to determine the thickness and depth of geologic layers using the velocity of seismic waves within the layers. The method is often used to map depths to specific horizons such as bedrock, clay layers, and the water table. In addition to mapping natural features, other secondary applications of the seismic methods include the location and definition of burial pits and trenches at hazardous waste sites.

A seismic source, geophones and a seismograph are required to make the measurements. The seismic source may be a simple sledgehammer with which to strike the ground. Explosives are frequently used for deeper applications. Geophones implanted in the ground translate the received vibrations of seismic energy into an electrical signal. This signal is displayed on the seismograph, permitting measurement of the arrival time of the seismic wave. The seismic velocities of the layers are then determined, and depth to the various layers are computed.

The Earth Resistivity Method

The earth resistivity method is used to measure the electrical resistivities of earth materials. The resistivity of a geological formation depends on grain size, porosity and cementation. Thus, resistivity can be used as a diagnostic parameter. For example, coarse-grained formations such as sand have high resistivity whereas fine-grained materials such as clay have low resistivities. The resistivity method is useful for determining the stratigraphic setting of a site. Introduction of inorganic contaminants into ground water lowers the resistivity of the saturated section. The resistivity method therefore, finds application in mapping contaminated groundwater.

The Electromagnetic (EM) Method

The EM method provides a means of measuring electrical conductivity of the subsurface. The parameter that is measured is the same as in the earth resistivity method. EM techniques are more efficient because no ground contact is required to make the measurements. This allows very rapid site investigation. Electrical conductivity is a function of the type of soil and rock, porosity, and water quality. Accordingly, the EM method is applicable both to the assessment of natural geohydrologic conditions and to mapping many types of contaminant plumes. Additionally, trench boundaries, buried wastes and drums can be located with EM techniques.

The Gravity Method

The gravity technique is used to map geological formations of different density. It finds application in mapping overburden thickness and is a very useful method for locating buried channels in bedrock. Bedrock channels influence the flow of groundwater and often provide a pathway for migration of contaminants from waste disposal sites. The gravity method is therefore a useful tool in evaluating the hydrogeology at and around landfill sites.

The Magnetometer

Magnetic measurements are commonly used to map regional geologic structure and to explore for minerals. They are also used to locate pipes and survey stakes or to map archaeological sites. MOE finds frequent use of the technique at industrial waste sites to locate buried drums and disposal material in trenches.

A magnetometer measures the intensity of the earth's magnetic field. The presence of ferrous metals creates variations in the local strength of that field, permitting their detection. A magnetometer's response is proportional to the mass of the ferrous target. Typically, a single drum can be detected at depths up to about 6 metres, while massive piles of drums can be detected at depths up to about 20 metres.

Geophysical Well-Logging

In geophysical well-logging methods, probes are lowered into a well by means of a cable, and a continuous record of geophysical parameters is obtained on a recorder at the surface. The parameters that are measured are:

- fluid conductivity;
- temperature;
- borehole diameter;
- formation resistivity;
- formation radioactivity.

The geophysical logs are used to determine porosity, permeability, moisture content and specific yield, and the source, movement and quality of water. Information obtained from information of geophysical logs is usually more objective and consistent than that from an examination of cuttings or cores. In addition, geophysical logs are often the only means of obtaining information from old wells and lateral extrapolation of geologic and hydrologic conditions. Well-logging has also proven to be an economical and useful tool in both designing and checking the construction of water wells and in optimizing well-performance.

DETAILS OF THE GEOPHYSICAL SURVEYS

1. GEOPHYSICAL MAPPING OF HYDROGEOLOGY AT THE BRACEBRIDGE LANDFILL SITE

An extensive hydrogeological investigation was undertaken near the Town of Bracebridge, following the discovery of trichloroethylene in the municipal water supply. The town is served by water wells which are located about 1 km south of the Bracebridge landfill site.

The consulting firm of Morrison Beatty and Associates was retained to carry out the hydrogeological investigation. The Ministry was responsible for providing the geophysical component of the investigation. Geophysics was required for proper definition of the hydrogeology of the area in order to allow correct placement of monitoring wells.

Seismic, resistivity and gravity surveys were completed. A well-defined bedrock channel was detected. This channel could provide a possible pathway for the migration of pollutants from the landfill site.

Proper locations for the installation of monitoring wells were identified.

FIGURE 1

GEOPHYSICAL MAPPING OF HYDROGEOLOGY AT THE BRACEBRIDGE LANDFILL SITE TO LOCATE SITES FOR MONITORING WELLS

2. GEOPHYSICAL MAPPING OF HYDROGEOLOGY AT THE GRAVENHURST LANDFILL SITE

The investigation at this site was necessitated by the appearance of a reddish-brown discolouration in the spring near the creek south of the landfill site. Leachate migrating from the landfill site was suspected as a possible cause of the problem. The hydrogeological investigation was conducted by the consulting firm of Gartner Lee and Associates, and the Ministry provided the geophysical survey.

Seismic, resistivity and gravity surveys were completed. Two buried bedrock channels which could provide possible pathways for the migration of leachate were detected.

Monitoring well locations were selected on the basis of the geophysical results.

FIGURE 2 GEOPHYSICAL MAPPING OF HYDROGEOLOGY AT THE GRAVENHURST LANDFILL SITE TO LOCATE SITES FOR MONITORING WELLS

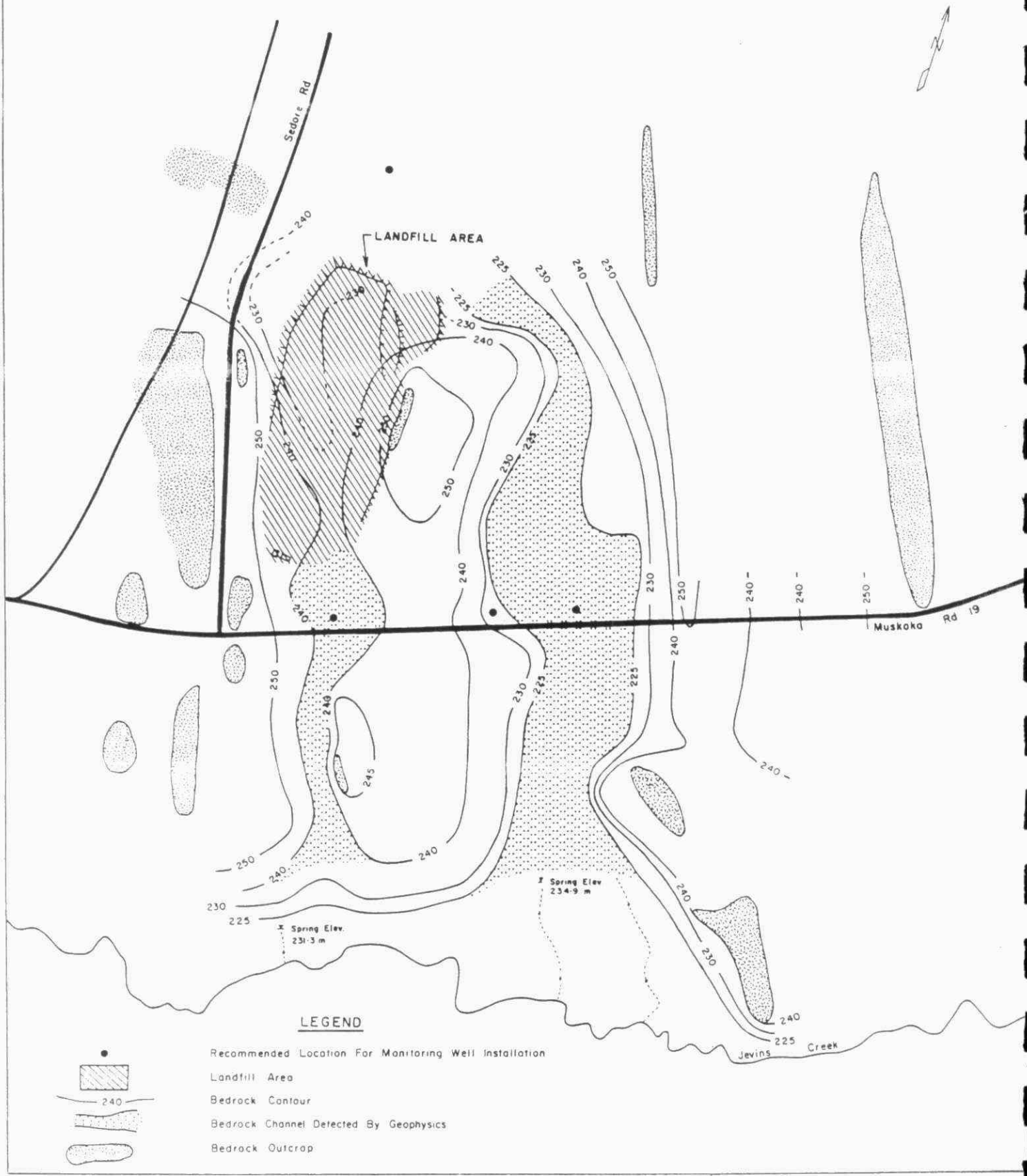
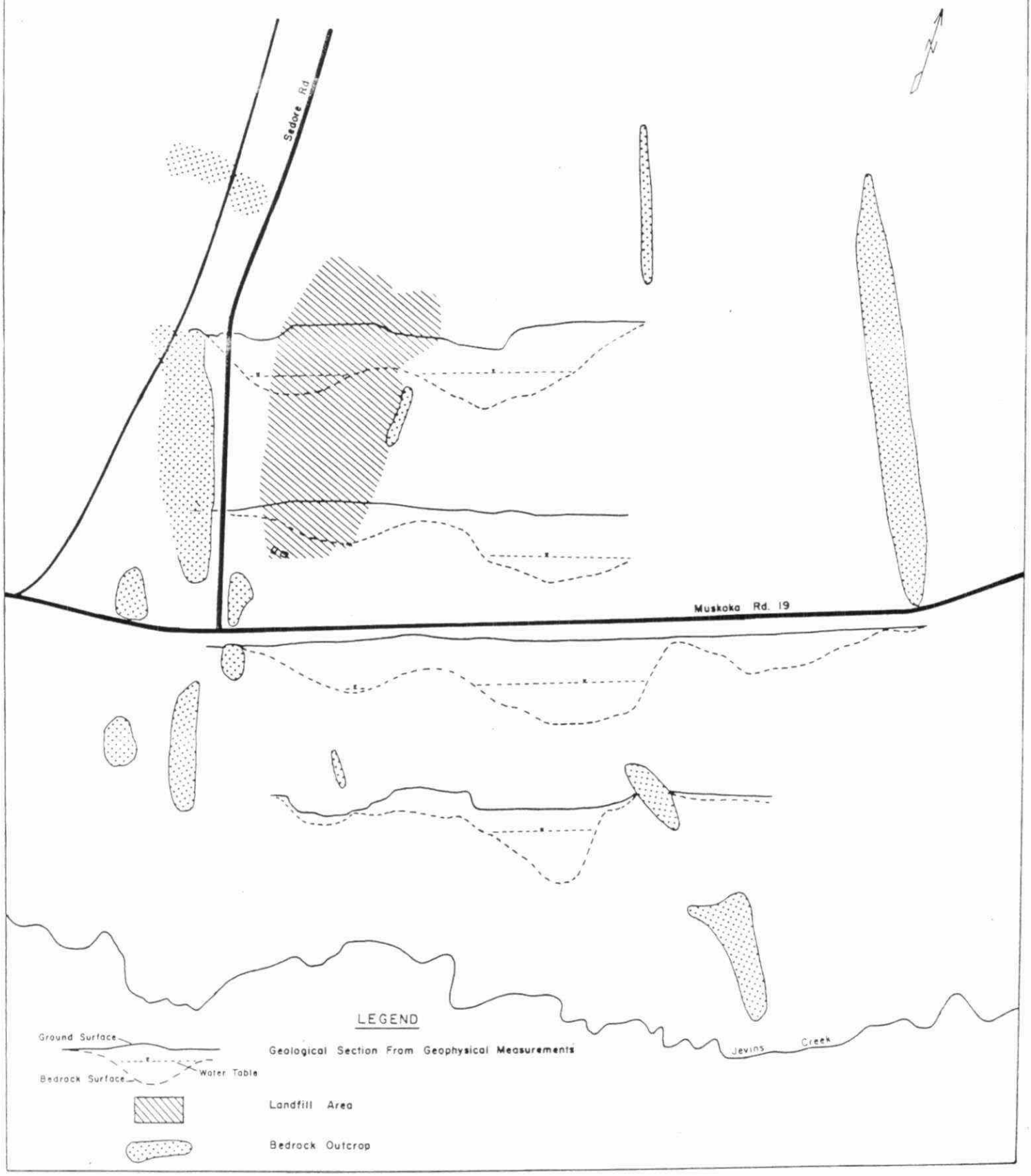


FIGURE 3 GEOPHYSICAL SECTIONS FROM GEOPHYSICAL MEASUREMENTS AT THE GRAVENHURST LANDFILL SITE



3. GEOPHYSICAL INVESTIGATION AT THE SITE OF THE WOODSTOCK COAL GASIFICATION SITE

The objective of the investigation was to locate any buried metal structures from the abandoned coal gasification site, and to map any waste contaminant plume. This was due to the discovery of a tar-like substance in an excavation for a building foundation near the site.

Magnetic and EM surveys were carried out. Areas where buried metal structures were located were outlined by magnetic surveying. EM results identified the presence of discrete sources of contamination.

Following the geophysical surveys, excavation of the buried objects and installation of monitoring wells was undertaken.

FIGURE 4 RESISTIVITY SURVEY TO MAP CONTAMINANT PLUME FROM THE WOODSTOCK COAL GASIFICATION SITE

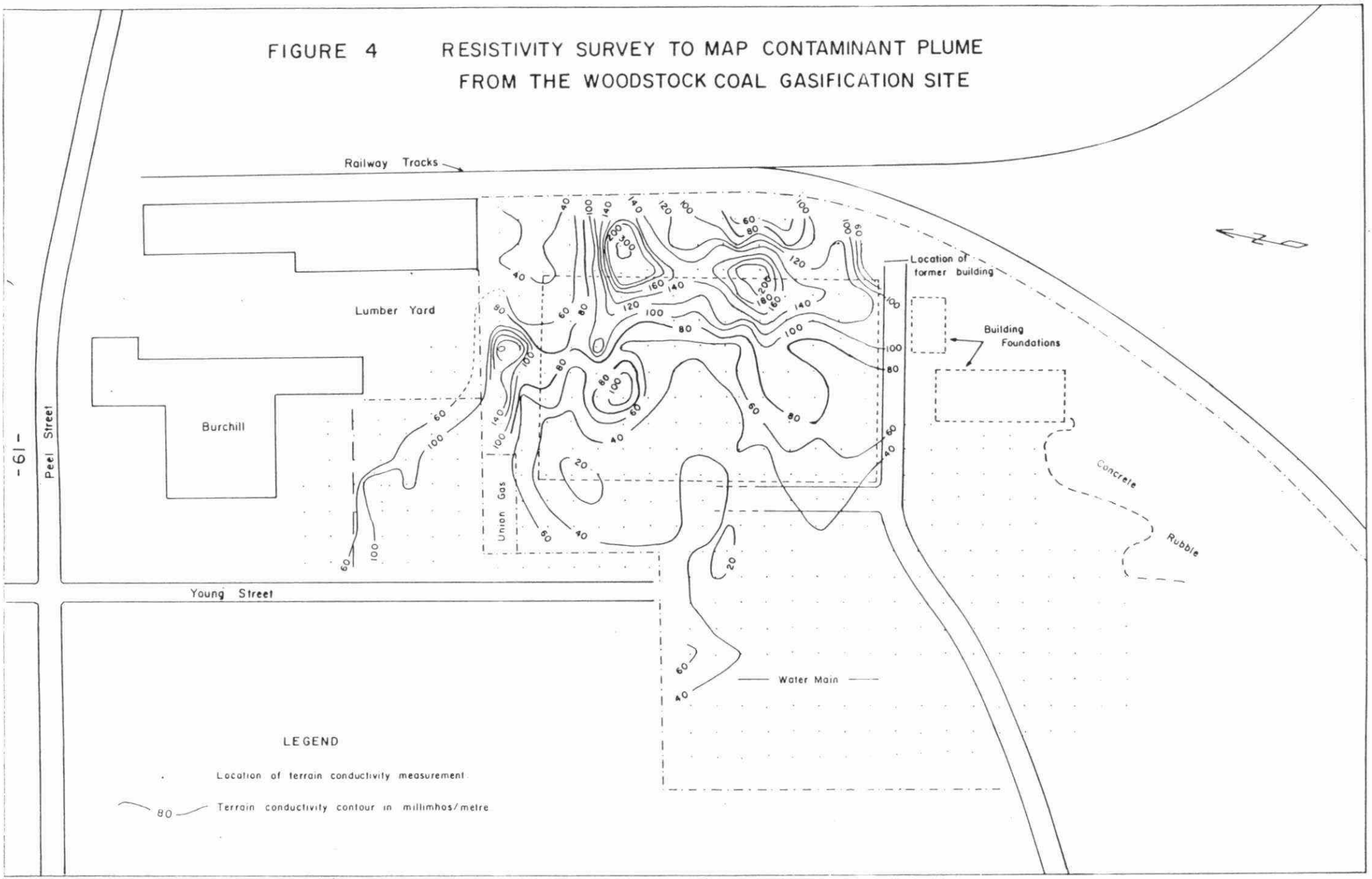
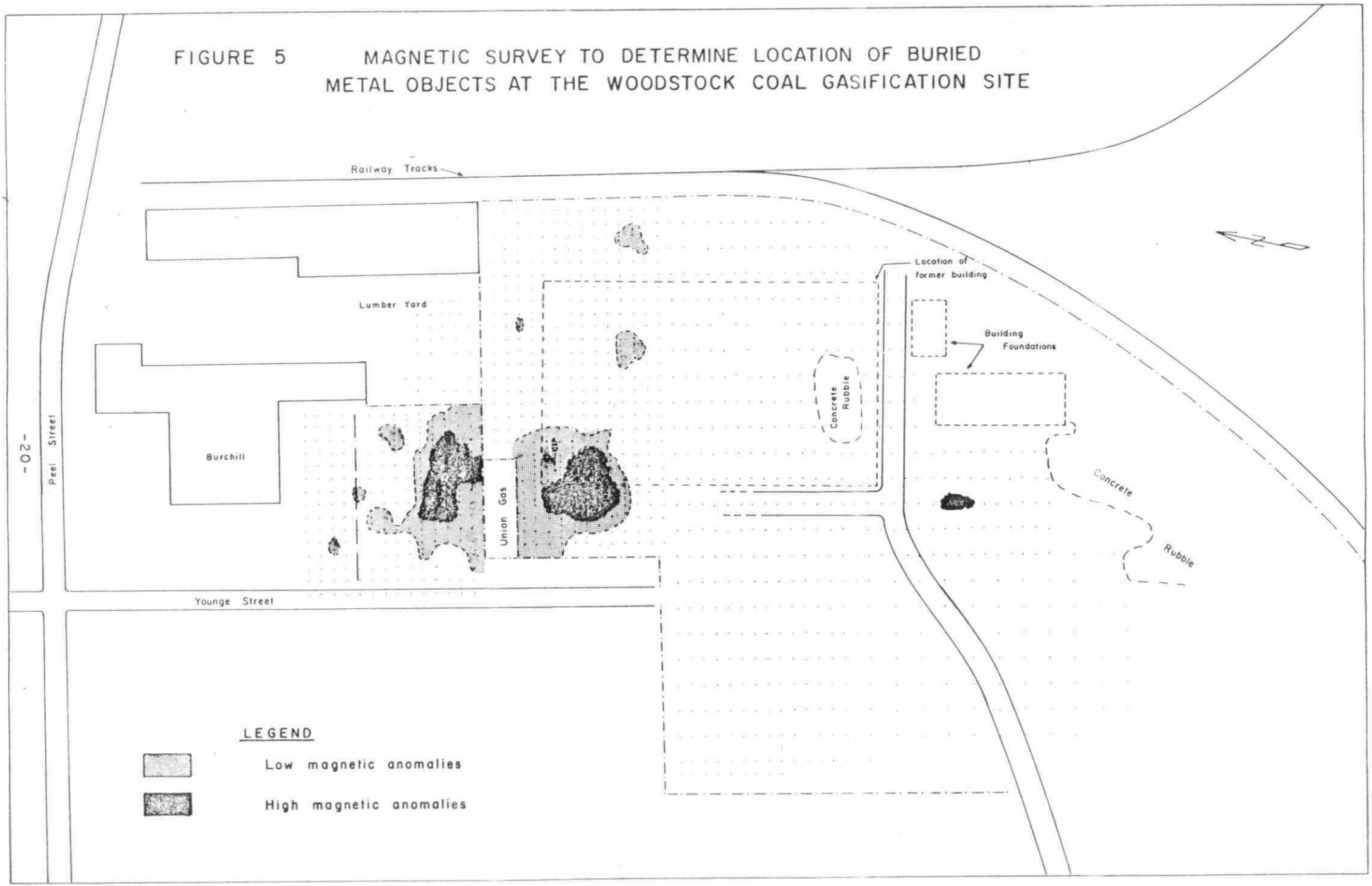


FIGURE 5 MAGNETIC SURVEY TO DETERMINE LOCATION OF BURIED METAL OBJECTS AT THE WOODSTOCK COAL GASIFICATION SITE



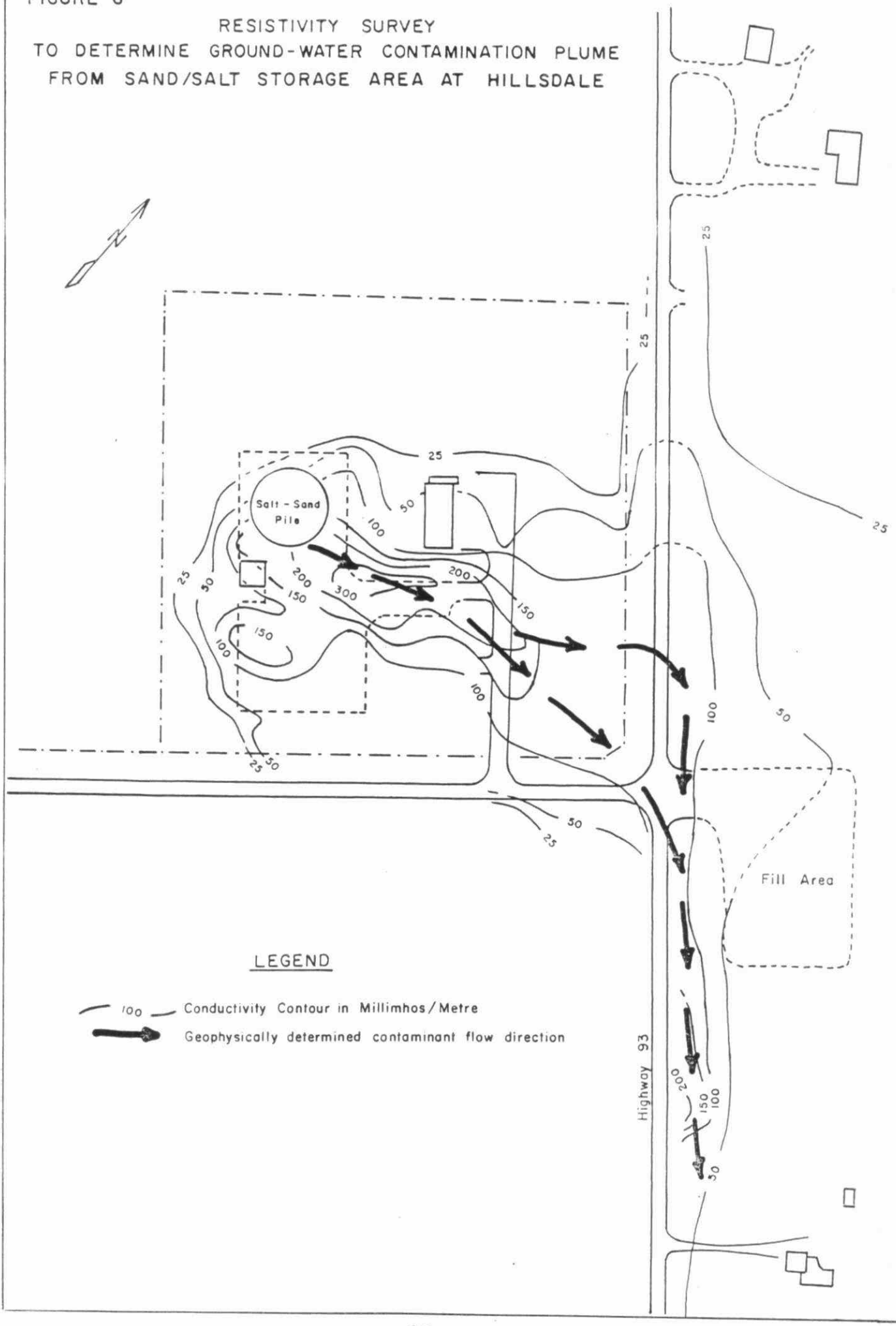
4. GEOPHYSICAL MAPPING OF GROUNDWATER CONTAMINATION AT THE HILLSDALE PATROL YARD

This survey was undertaken at the request of the Ministry of Transportation and Communications (MTC). An uncovered sand/salt pile was maintained at the Hillsdale patrol yard for several years. This resulted in significant contamination of groundwater. The purpose of the geophysical survey was to outline the area of groundwater contamination.

The results of the geophysical survey showed that groundwater contamination has spread to private property beyond the patrol yard boundary. This information was used by MTC to assess claims for damage to groundwater resources on private property.

FIGURE 6

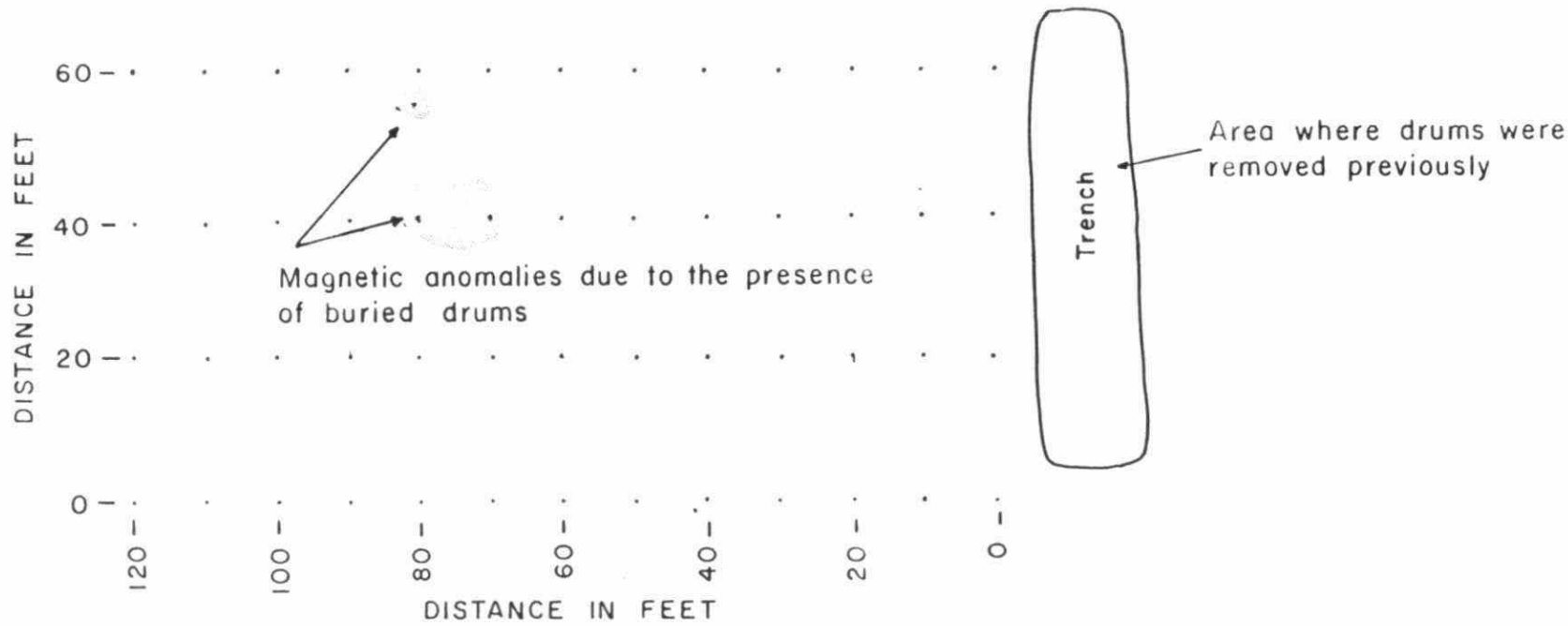
RESISTIVITY SURVEY
TO DETERMINE GROUND-WATER CONTAMINATION PLUME
FROM SAND/SALT STORAGE AREA AT HILLSDALE



5. MAGNETOMETER SURVEY TO LOCATE BURIED WASTE DISPOSAL DRUMS AT AN UNLICENSED SITE NEAR WATERDOWN

A magnetometer survey was undertaken to locate illegally buried waste drums at a site near Waterdown. The drums contained fibre-glass resins and other industrial waste products. Several buried drums were located and excavated. The magnetometer survey was indispensable for proper site clean-up.

FIGURE 7 MAGNETIC SURVEY TO LOCATE INDUSTRIAL WASTES BURIED IN DRUMS NEAR WATERDOWN



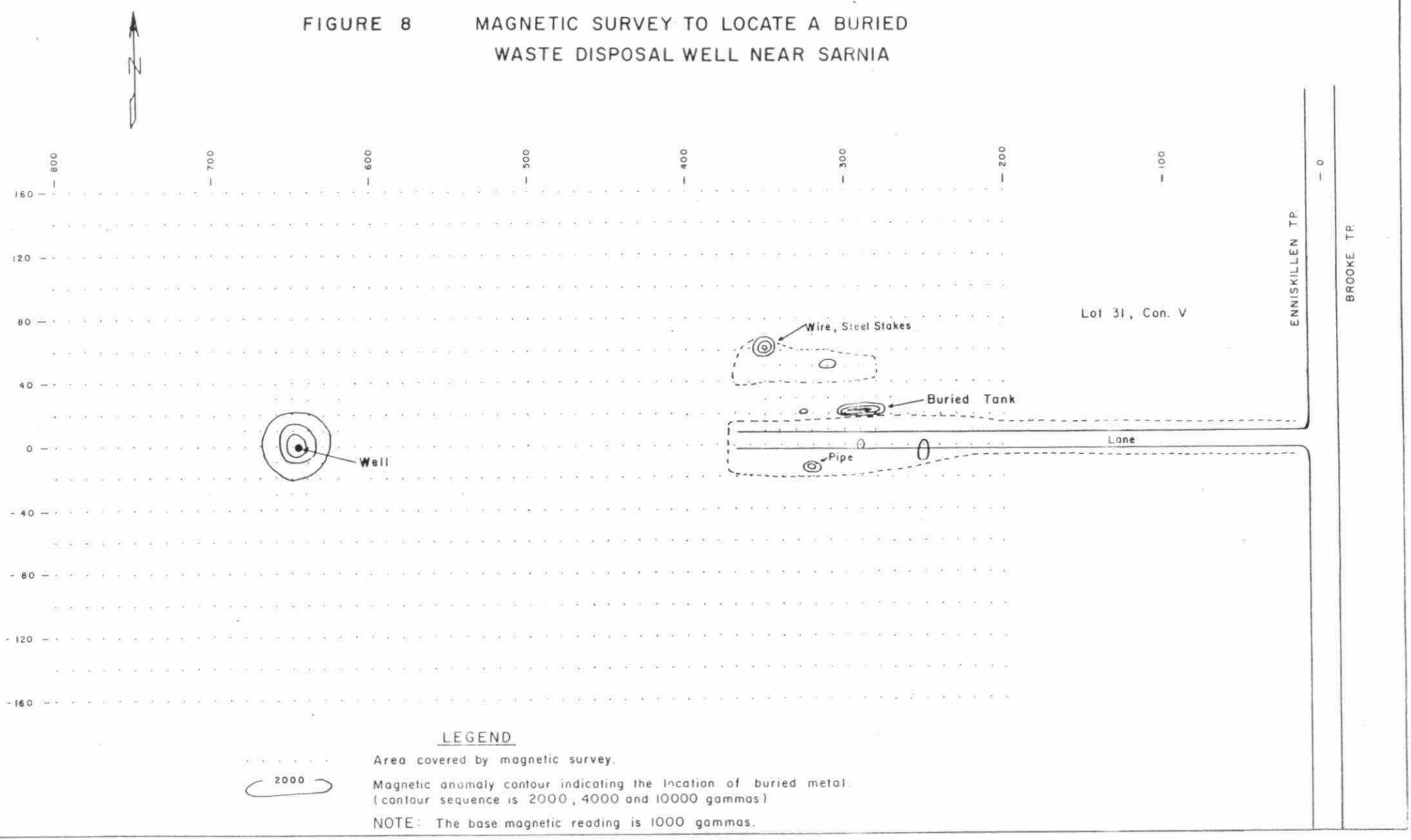
NOTE: Site located on Smith Farm, Lot 1 Con 2 Flamborough Township.

6. LOCATION OF A BURIED DEEP DISPOSAL WELL NEAR SARNIA

A magnetometer survey was undertaken to locate a buried deep disposal well near Sarnia. This well was used to dispose industrial liquid wastes in the past and has since been abandoned, but it was not properly sealed. The exact location of the well was not known. The magnetometer survey was successful in locating the well. The correct abandonment of the well was then conducted.

An abandoned buried storage tank full of industrial wastes was also located during the search for the disposal well. Excavation of the tank and disposal of the liquid wastes and contaminated soil will be undertaken when weather permits.

FIGURE 8 MAGNETIC SURVEY TO LOCATE A BURIED WASTE DISPOSAL WELL NEAR SARNIA



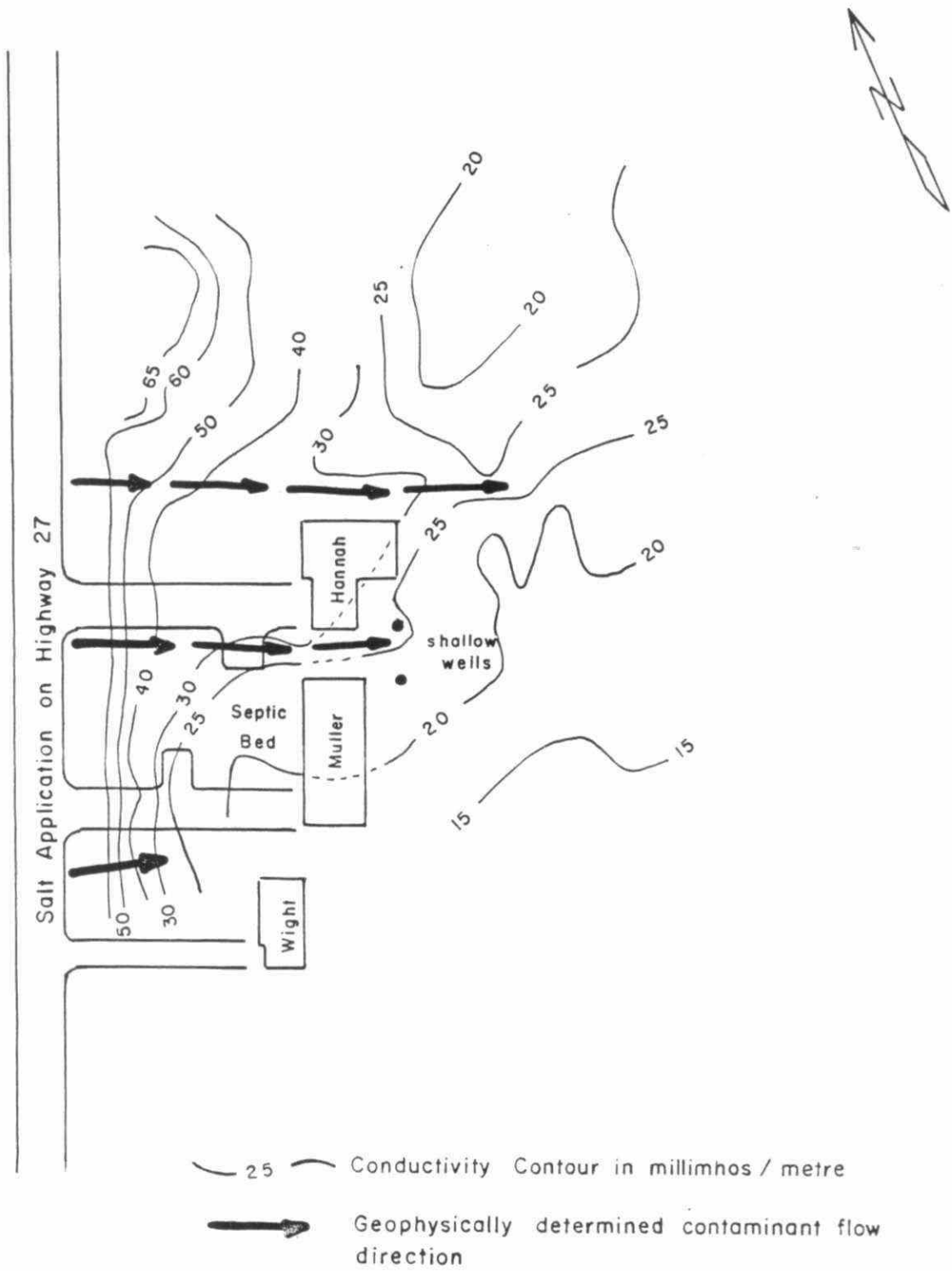
7. GEOPHYSICAL MAPPING OF SALT CONTAMINATION OF GROUNDWATER DUE TO HIGHWAY SALTING NEAR BARRIE

This survey was carried out at the request of Central Region, following complaints from a well owner about a salty taste in his well water. The well is located near Highway 27. Highway salting was suspected as a possible cause of the problem. Another possible cause was contamination from waste discharge from the water softener.

The geophysical survey outlined the area of contamination along the highway. The geophysical results show clearly that the well was impacted by road salting along the highway. A replacement well was drilled.

FIGURE 9

RESISTIVITY SURVEY TO MAP CONTAMINANT PLUME FROM ROAD SALT IN INNISFIL TOWNSHIP

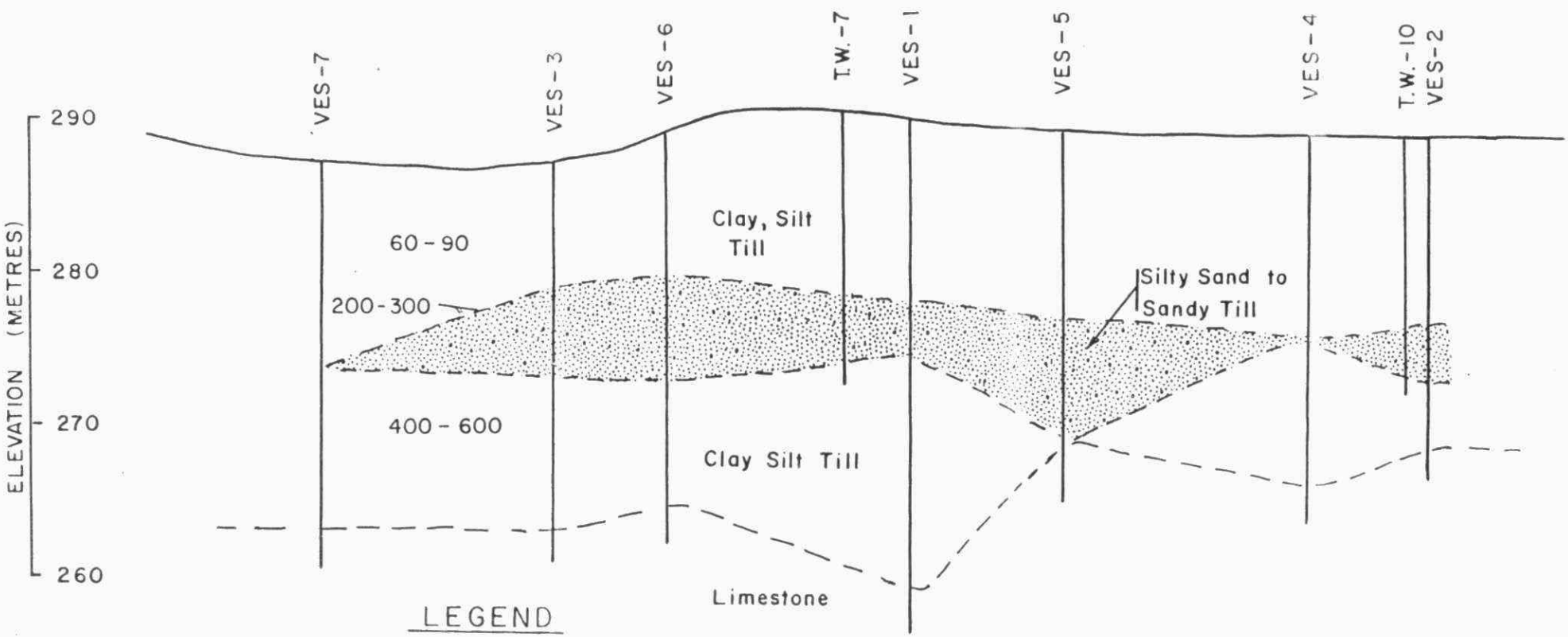


8. GEOPHYSICAL MAPPING OF HYDROGEOLOGY IN THE HENSALL AREA

The purpose of the geophysical survey was to map the hydrogeology of the area in order to allow the location of monitoring wells to determine the migration of nitrate to the municipal well at Hensall. This work was carried out at the request of the Southwestern Region. The mapping was accomplished using the resistivity technique. Target areas for the installation of monitoring wells were identified.

FIGURE 10

RESISTIVITY MAPPING OF FORMATIONS IN THE VILLAGE OF HENSALL TO DETERMINE THE MECHANISM OF NITRATE CONTAMINATION OF GROUND WATER



LEGEND

VES — Vertical electrical sounding.

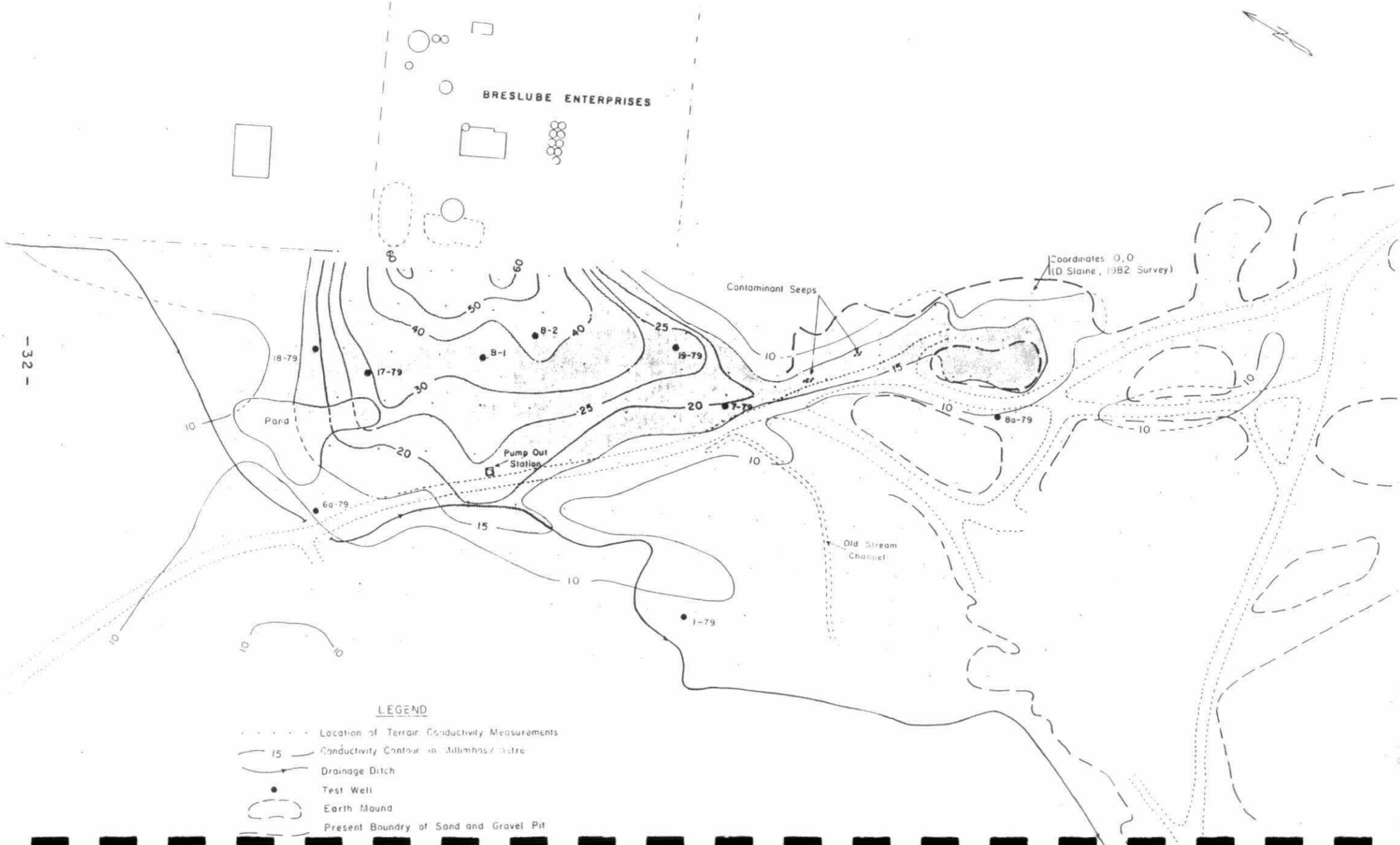
200 – 300 — Range of resistivity values in ohm-metres as measured by vertical electrical soundings.

9. GEOPHYSICAL MAPPING OF CONTAMINANT PLUME AROUND WASTE OIL TREATMENT PLANT IN BRESLAU

The purpose of the geophysical survey was to map a contaminant plume around the Breslube Enterprises plant. Waste oil and sludge was stored in unlined lagoons, and contaminants from the lagoons seeped to the groundwater table and migrated towards the Grand River.

The resistivity survey outlined the area of contamination and enabled piezometers to be installed to monitor the migration of the plume.

FIGURE II RESISTIVITY SURVEY TO MAP GROUND-WATER CONTAMINATION FROM A WASTE-OIL TREATMENT FACILITY IN BRESLAU



10. DETERMINATION OF ZONES OF POOR WATER-QUALITY IN A DOMESTIC WELL NEAR ORILLIA

A domestic well located in the Township of Orillia and drilled to a depth of 193 ft yielded water of poor quality. Geophysical well-logging was carried out to determine whether there were any fresh water-bearing zones in the upper section of the well. If there were fresh water zones, then the well could be salvaged by sealing off the zone of poor-quality water.

Single-point resistance, temperature and fluid conductivity logs were recorded. The logs yielded information on lithology and well hydraulics. They also confirmed the existence of only one major water-bearing zone in the well. This zone yielded poor quality water. Thus, further expenditure in trying to salvage the well by plugging was not warranted. The well was then abandoned.

FIGURE 12 GEOPHYSICAL LOGGING TO DETERMINE WATER QUALITY IN DOMESTIC WELL NEAR ORILLIA